

Sulfur Dioxide Concentrations

Sulfur dioxide (SO₂) is one of many sulfur oxide gases that form during the combustion of fuels containing sulfur, primarily coal and oil. The largest anthropogenic source of SO₂ emissions in the U.S. is fossil fuel combustion at electric utilities and other industrial facilities. SO₂ is also emitted from certain manufacturing processes and mobile sources, including locomotives, large ships, and construction equipment (see [SO₂ Emissions indicator](#)). The highest concentrations of SO₂ are typically recorded in the vicinity of large emissions sources.

Short-term exposure to airborne SO₂ has been associated with various adverse health effects (U.S. EPA, 1994; ATSDR, 1998). Multiple human clinical studies, epidemiological studies, and toxicological studies support a causal relationship between short-term exposure to airborne SO₂ and respiratory morbidity. The observed health effects have included decreased lung function, respiratory symptoms, and increased emergency department visits and hospitalizations for all respiratory causes. These studies further suggest that asthmatics, children, older adults, and people who spend a lot of time outdoors at increased exertion levels are potentially susceptible or vulnerable to these health effects (U.S. EPA, 2008b). In addition, SO₂ reacts with other air pollutants to form sulfate particles, which are constituents of fine particulate matter (PM_{2.5}). Inhalation exposure to PM_{2.5} has been associated with various cardiovascular and respiratory health effects (see [PM Concentrations indicator](#)).

Airborne SO₂ also causes or contributes to numerous environmental impacts. For instance, airborne SO₂ along with airborne nitrogen oxides contributes to acidic deposition, and this deposition can harm susceptible aquatic and terrestrial ecosystems, including injury to forests and changes in the composition of fish and other aquatic species (see [Acid Deposition indicator](#)). In some watersheds, sulfate deposition increases mercury methylation rates, which leads to formation of methylmercury—the chemical form of mercury that accumulates in the aquatic food chain (EPA, 2008a). In addition, SO₂ contributes to the formation of fine airborne particles that can impair visibility—an issue of particular concern in National Parks and Wilderness Areas (see [Regional Haze indicator](#)).

This indicator presents ambient SO₂ concentrations in parts per billion (ppb) from 1978 to 2013 using two averaging times: 1-hour averaging times to be consistent with the current primary National Ambient Air Quality Standard (NAAQS) and annual averaging times to present trends in long-term exposure levels. Trend data are based on measurements from the State and Local Air Monitoring Stations network and from other special purpose monitors. The number and spatial coverage of monitoring sites depend on the time horizon for the trends: for 1980 through 2013, 86 monitoring sites in 76 counties nationwide have sufficient data to characterize annual average trends; and for 1998 through 2013, 221 monitoring sites in 159 counties nationwide have sufficient data to characterize 1-hour trends. Trends are displayed for the entire nation and for each EPA Region. Refer to the technical documentation for the selection criteria that were applied to identify the sites with sufficient data to characterize air quality trends.

Trends in 1-hour SO₂ concentrations are presented for the annual 99th percentile 1-hour daily maximum, averaged over 3 consecutive years. This averaging time and statistic is consistent with the primary NAAQS, which was derived to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly. All exhibits in this indicator present the SO₂ NAAQS as a point of reference. The exhibits showing trends in 1-hour concentrations display the current NAAQS. The fact that the national or regional concentrations fall below the standards

does not mean that all monitoring sites nationally or in any EPA Region also are below the standards. The indicator displays trends in the number of trend sites nationwide at which SO₂ concentrations exceeded the level of the standards, but these statistics are not displayed for each EPA Region.

What the Data Show

Annual average SO₂ concentrations at 86 monitoring sites decreased by 87 percent between 1980 and 2013, and the 2013 levels are the lowest over the 34-year period of record (Exhibit 1). Annual average SO₂ levels have also steadily decreased in every EPA Region, with the greatest reductions (92 percent) observed in Region 4 and Region 6 (Exhibit 2). This downward trend in annual SO₂ concentrations parallels the downward trend observed in SO₂ emissions from 1990 to 2011, which has been attributed largely to decreased emissions from electric utilities (the [SO₂ Emissions indicator](#)). Decreased emissions from mobile sources due to use of low-sulfur fuels has also contributed to the ambient concentration trend.

The annual 99th percentile of daily maximum 1-hour SO₂ concentrations, averaged over 3 consecutive years, also exhibited a downward trend. These data were displayed for two different time horizons in order to account for as many monitoring sites as possible, because more sites meet the site selection criteria when considering more recent, shorter time frames:

- For 1978 to 2013, the 3-year average of the 99th percentile of daily maximum 1-hour SO₂ concentrations decreased by 79 percent across the 27 sites with sufficient data (Exhibit 3). Among these sites, the number reporting concentrations above the level of the 1-hour NAAQS decreased by 87 percent (Exhibit 4).
- For 1998 to 2013, the 3-year average of the 99th percentile of daily maximum 1-hour SO₂ concentrations decreased by 60 percent across the 221 sites with sufficient data (Exhibit 5). Among these sites, the number reporting concentrations above the level of the 1-hour NAAQS decreased by 79 percent (Exhibit 6). Consistent with the nationwide trend, the 99th percentile of daily maximum 1-hour SO₂ concentrations averaged over 3 consecutive years also steadily decreased between 1998 and 2013 in the EPA Regions, with the greatest percent reduction observed in Region 2 (Exhibit 7).

Also shown in Exhibit 1, 3, and 5 are the 90th and 10th percentiles based on the annual measurements at the monitoring sites. This provides additional graphical representation of the variability of measured concentrations across the monitoring sites for a given year. The shaded areas in these exhibits display the concentration range where 80 percent of measured values occurred for that year.

Limitations

- Because most SO₂ monitoring sites are in urban areas, the trends might not accurately reflect conditions outside the immediate urban monitoring areas.
- Because of the relatively small number of trend sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa. In addition, the trend sites in this indicator are not dispersed uniformly across all states in the EPA Regions. The 221 sites for the 1998-2013 trends are located in 36 states and the District of Columbia. In the remaining 14 states, there currently are insufficient long-term data from the existing monitoring sites to include in this indicator.

- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of SO₂ monitoring sites with sufficient data to assess trends since 1978. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported SO₂ concentrations above the level of the NAAQS over the time frame covered by this indicator. In 2013, 31 sites in the U.S. measured SO₂ concentrations above the level of the 1-hour NAAQS: this includes the 21 trend sites shown in Exhibit 6, and 10 sites that did not have sufficient long-term data to be included in this indicator.
- Because of the relatively small number of trend sites for the long-term period 1980-2013, the national trends in Exhibits 1-4 may not necessarily be representative of the entire U.S.

Data Sources

Summary data in this indicator were provided by EPA's Office of Air Quality Planning and Standards, based on SO₂ ambient air monitoring data in EPA's Air Quality System (U.S. EPA, 2014a) (<https://www.epa.gov/aqs>). National and regional trends in this indicator are based on the subset of SO₂ monitoring stations that have sufficient data to assess trends.

References

ATSDR (Agency for Toxic Substances and Disease Registry). 1998. Toxicological profile for sulfur dioxide. Atlanta, GA. <http://www.atsdr.cdc.gov/ToxProfiles/tp116.pdf> (PDF) (223 pp, 3.5MB).

U.S. EPA (United States Environmental Protection Agency). 2014a. Data from the Air Quality System. Accessed 2014. <https://www.epa.gov/aqs>

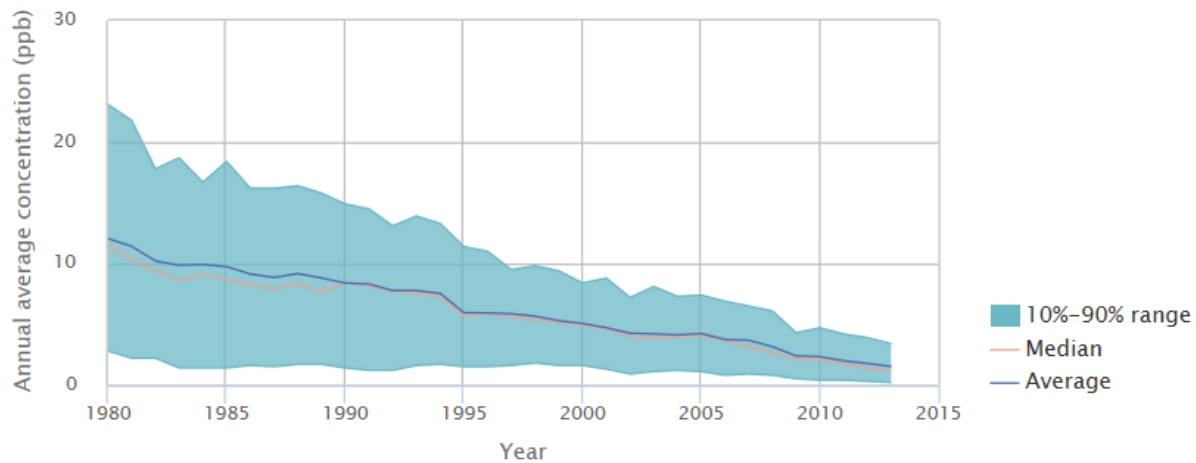
U.S. EPA. 2014b. History of the national ambient air quality standards for oxides of sulfur. http://www3.epa.gov/ttn/naaqs/standards/so2/s_so2_history.html.

U.S. EPA. 2008a. Integrated science assessment for oxides of nitrogen and sulfur – ecological criteria. EPA/600/R-08/082F. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=201485>.

U.S. EPA. 2008b. Integrated science assessment for sulfur oxides – health criteria. EPA/600/R-08/047FA. Research Triangle Park, NC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=198843>.

U.S. EPA. 1994. Supplement to the second addendum (1986) to air quality criteria for particulate matter and sulfur oxides (1982): Assessment of new findings on sulfur dioxide and acute exposure health effects in asthmatic individuals. EPA/600/FP-93/002. Washington, DC. <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=96580>

Exhibit 1. Ambient annual SO₂ concentrations in the U.S., 1980–2013



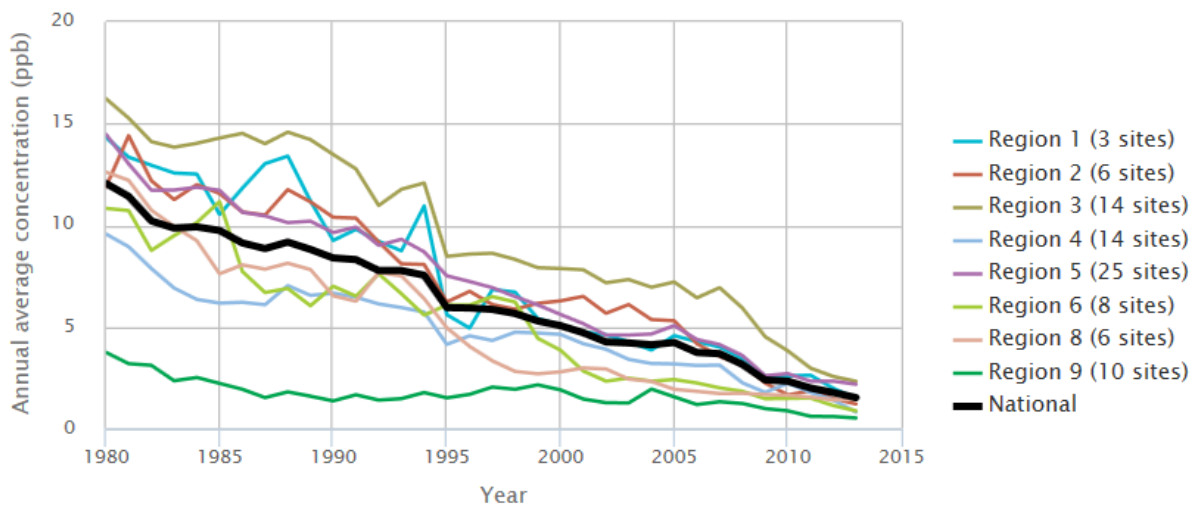
Coverage: 86 monitoring sites in 76 counties nationwide (out of a total of 428 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1980.

In 2010, the annual average SO₂ NAAQS (30 ppb) was revoked (U.S. EPA, 2014b).

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 2. Ambient annual SO₂ concentrations in the contiguous U.S. by EPA Region, 1980–2013



Coverage: 86 monitoring sites in 76 counties nationwide (out of a total of 428 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1980.

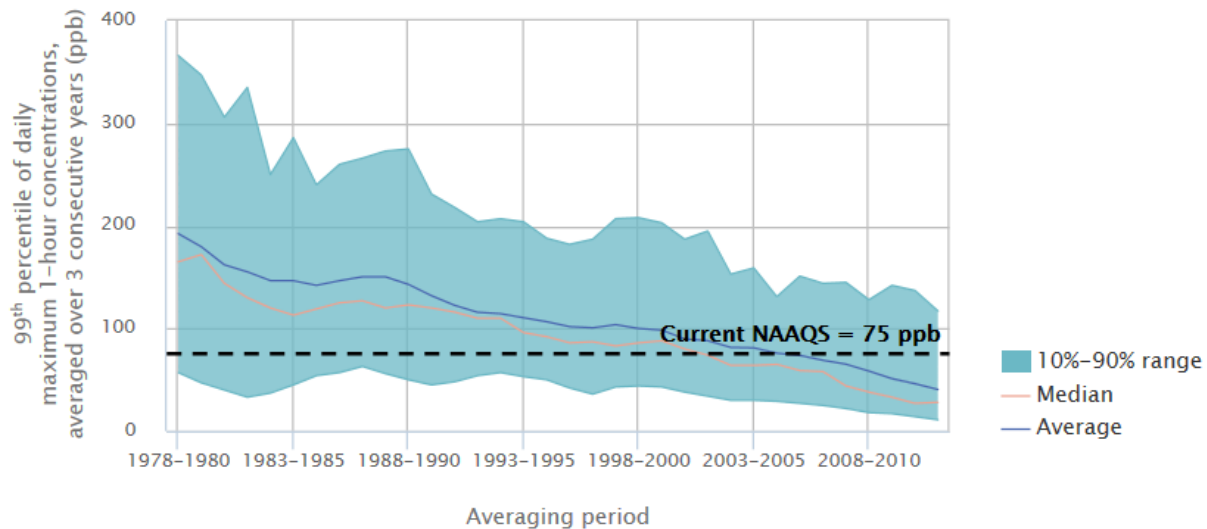
States in Regions 7 and 10 have removed SO₂ monitors in recent years because of low concentrations, and consequently none of these Regions' monitoring sites has a complete record dating back to 1980. Thus, no trend lines for Regions 7 and 10 are shown.

In 2010, the annual average SO₂ NAAQS (30 ppb) was revoked (U.S. EPA, 2014b).

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 3. Ambient 1-hour SO₂ concentrations in the U.S., 1978–2013



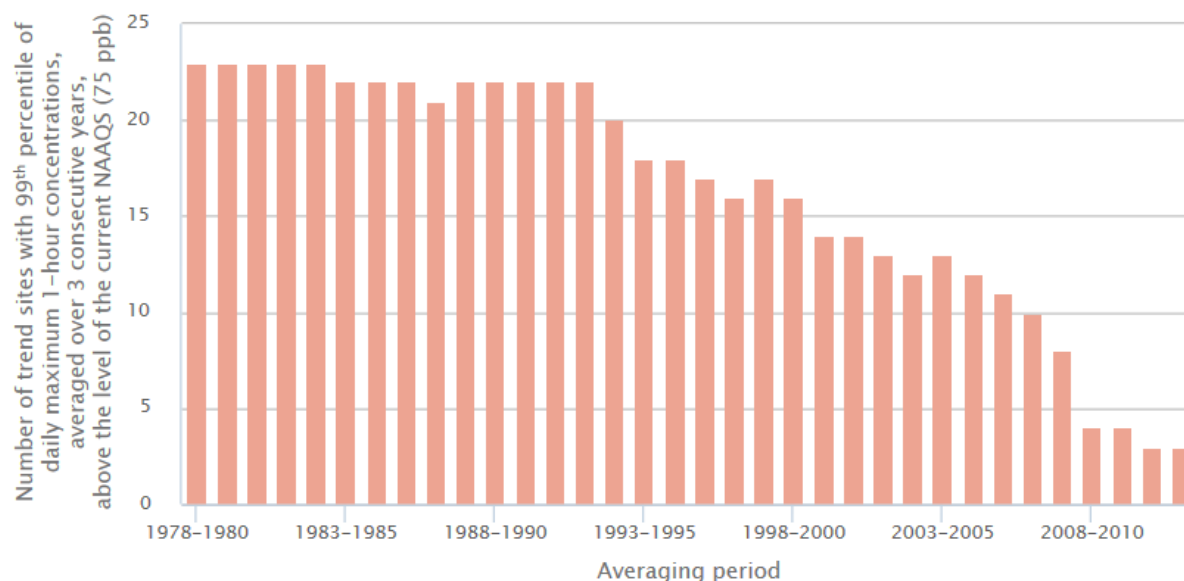
The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2014b).

Coverage: 27 monitoring sites in 27 counties nationwide (out of a total of 389 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1978.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 4. Ambient 1-hour SO₂ concentrations above the level of the current NAAQS in the U.S., 1978–2013



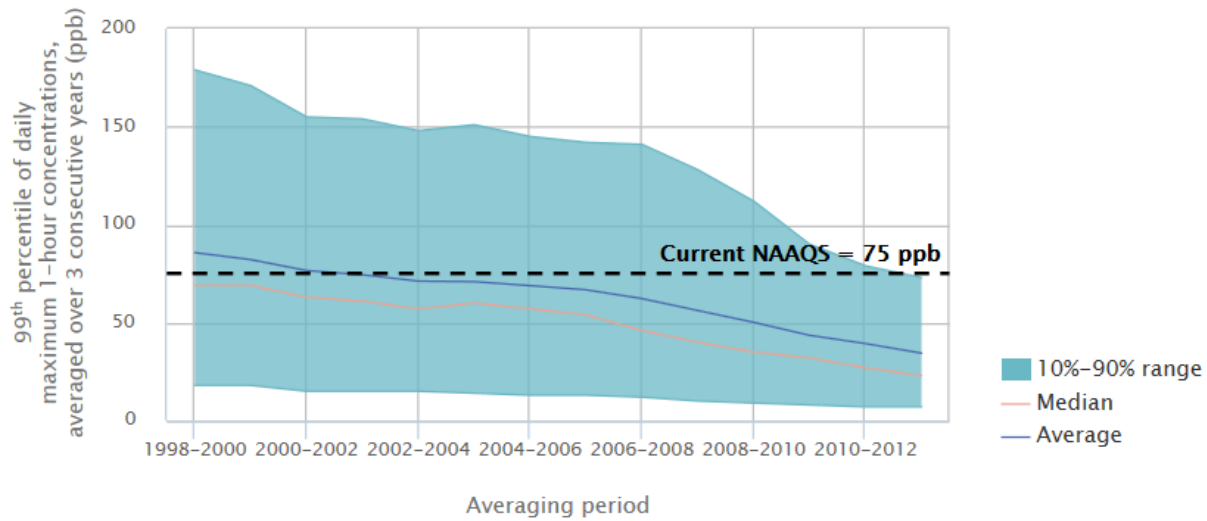
The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2014b).

Coverage: 27 monitoring sites in 27 counties nationwide (out of a total of 389 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1978.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 5. Ambient 1-hour SO₂ concentrations in the U.S., 1998–2013



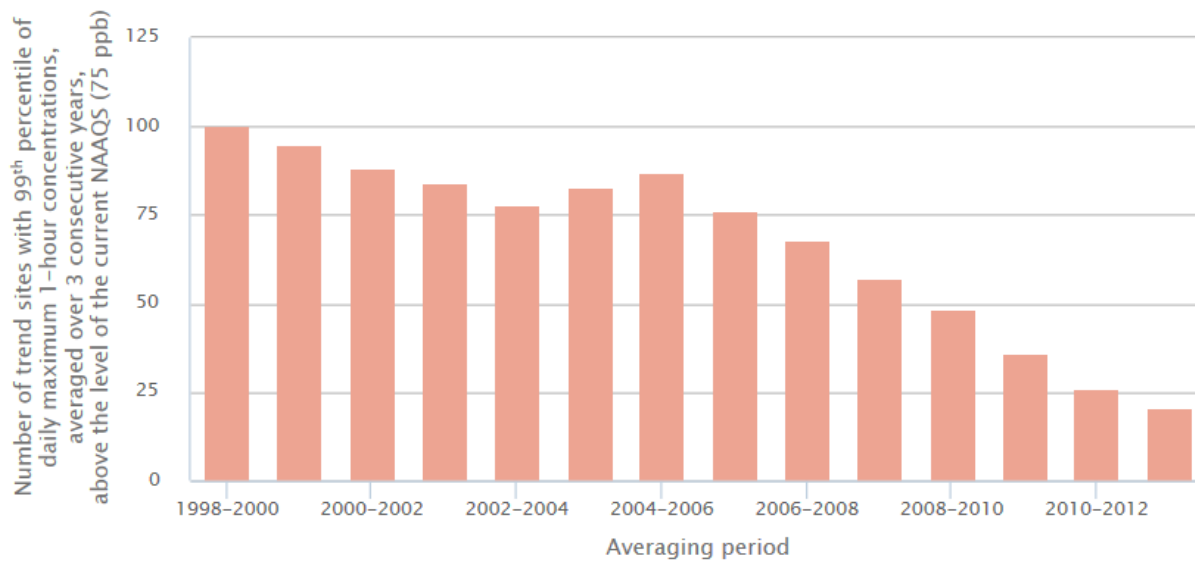
The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2014b).

Coverage: 221 monitoring sites in 159 counties nationwide (out of a total of 389 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1998.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 6. Ambient 1-hour SO₂ concentrations above the level of the current NAAQS in the U.S., 1998–2013



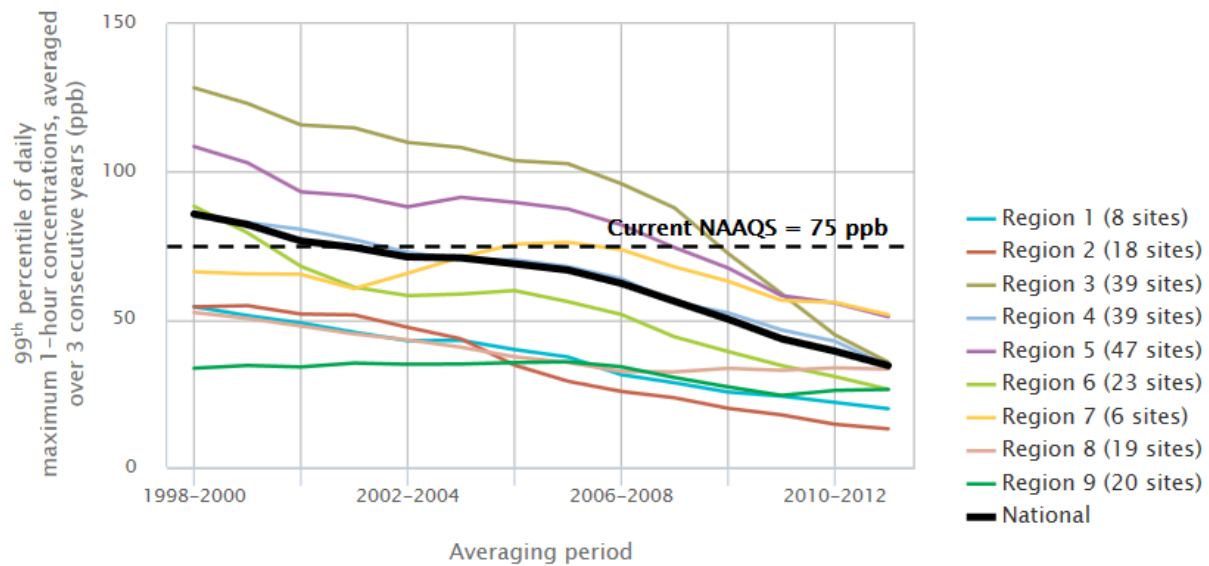
The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2014b).

Coverage: 221 monitoring sites in 159 counties nationwide (out of a total of 389 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1998.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a

Exhibit 7. Ambient 1-hour SO₂ concentrations in the contiguous U.S. by EPA Region, 1998–2013



The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2014b).

Coverage: 219 monitoring sites in 159 counties in the EPA Regions (out of a total of 389 sites measuring SO₂ in 2013) that have sufficient data to assess SO₂ trends since 1998.

States in Region 10 have removed SO₂ monitors in recent years because of low concentrations, and consequently none of this Region's monitoring sites has a complete record dating back to 1980. Thus, no trend line for Region 10 is shown.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2014a